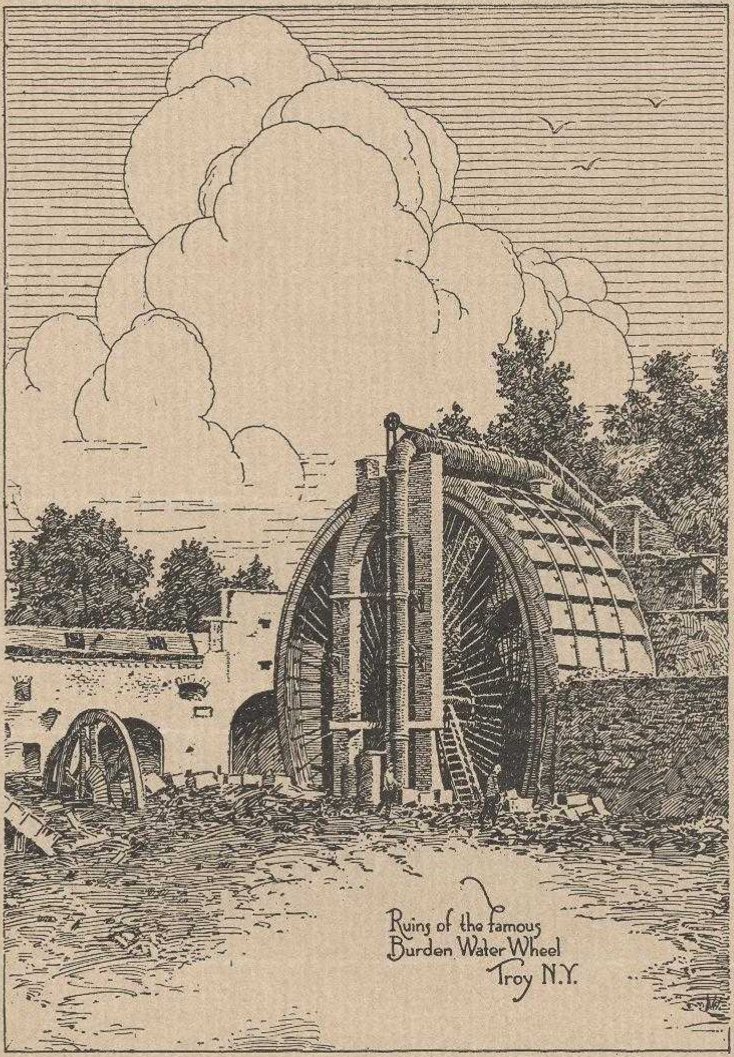
TECHNICAL DEPARTMENT

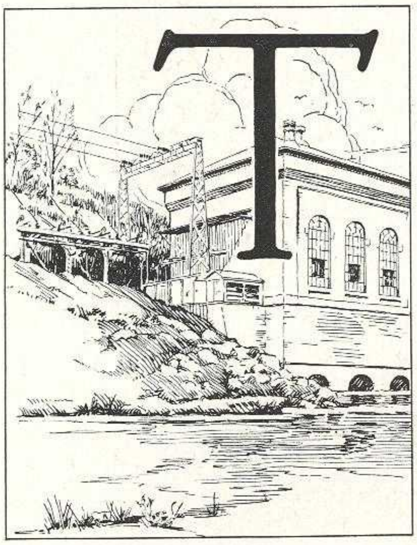


Ruins of the famous
Burden Water Wheel
Troy N.Y.

VERTICAL SHAFT WATER WHEEL DRIVEN GENERATORS

Vertical Shaft Waterwheel-Driven Generators

POWER



THE existence and progress of modern civilization is dependent upon a constantly available supply of cheap power. Fuel is, and has been, the principal source of power, but the supply of all known fuels is limited and rapidly being exhausted. Water furnishes a substantial portion of the power supply and, unlike coal, its use does not reduce the total supply. In fact, undeveloped water power is going to waste and its potential energy is lost forever, while the national coal pile is being reduced to take the place of this waste.

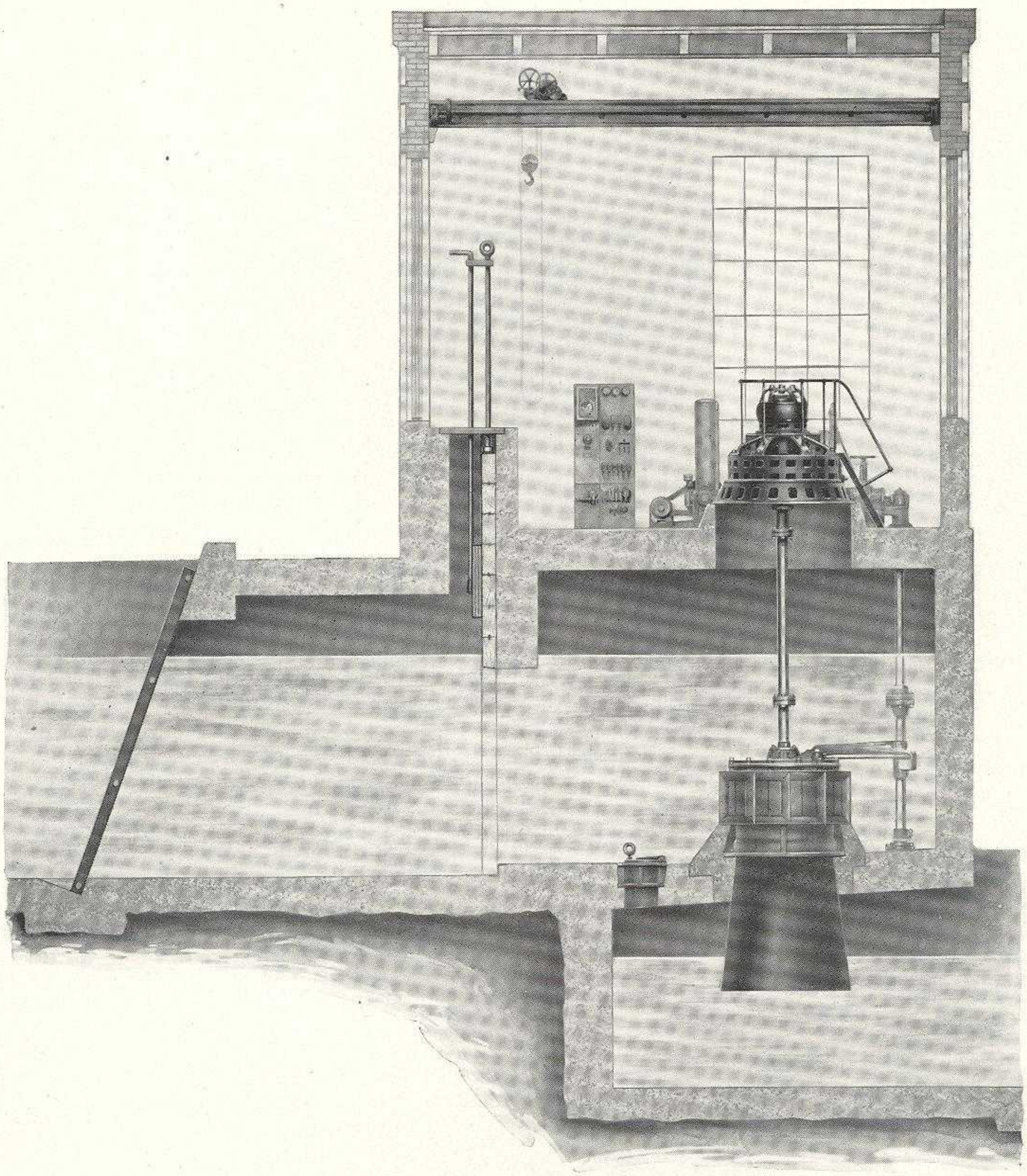
The rapidly increasing price of coal is compelling the development of the smaller and more inaccessible supplies of water power and also the supplanting of old units by modern and more efficient machines. Modern electrical equipment has made practicable the development of much water power that would otherwise go to waste, for the power can be developed at the dam in some remote spot and consumed where most convenient. In fact, generating plants are now in operation designed by the General Electric Company to run successfully with no operators whatever.

The more accessible large supplies of water power have been largely developed, but there remains a vast quantity of easily available water power suitable for driving small and medium-sized generators. In addition to these undeveloped sites, there are many old plants consisting of horizontal shaft generators driven by long shafts geared or belted to waterwheels. These shafts have been sprung out of line, the gears have become worn and broken, the efficiency of the waterwheels, originally poor, has become worse due to wear and corrosion until, at present, some of these old installations can convert into electrical energy only half the available energy of the water. The gears and belts not only occupy much valuable space but they waste energy, are noisy, and a constant source of annoyance and expense.

Remarkable developments have been made in the past few years in the design and manufacture of vertical shaft waterwheels for low heads. These turbines combined with the modern vertical shaft generators make units that are far simpler, more reliable and more efficient than the old type of installation.

In the manufacture of these generators the General Electric Company with its splendid manufacturing facilities, large corps of expert specialists and wide experience, stands pre-eminent. This bulletin describes the line of standard vertical waterwheel-driven generators from 62.5 kv-a. to 3000 kv-a. capacities, manufactured by this Company. As a result of experience extending over a quarter of a century in the design, construction and installation of waterwheel-driven generators, the General Electric Company is now producing units ranging in capacities from 30 kv-a. to 65,000 kv-a. The total capacity of such machines now in successful operation is considerably in excess of 4,000,000 kw.

In addition to waterwheel-driven generators, the General Electric Company manufactures all classes of electrical apparatus necessary for the complete equipment of hydro-electric stations, and the services of the Company's engineers are always at the disposal of prospective customers to assist in selecting apparatus which will insure safety and reliability in operation, and the most efficient utilization of the water power.



SECTION OF TYPICAL HYDRO-ELECTRIC STATION

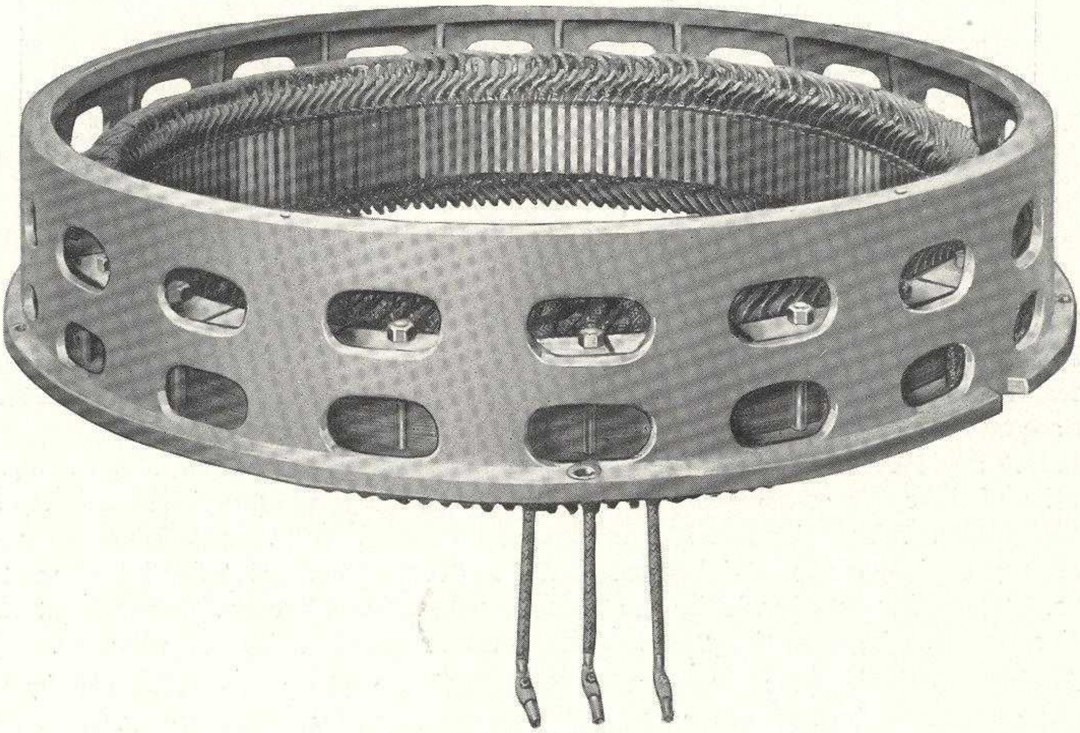
The illustration above, in addition to giving an idea of the conventional arrangement of the apparatus in a typical small hydro-electric generating station, shows how simple and inexpensive a type of construction can be employed in the forebay, tailrace, etc., and in the building which houses the electrical apparatus. The simple construction is worthy of emphasis because it is often a deciding economic factor in the projected development of water power sites. The same arrangement of apparatus and building layout apply to both automatically and manually controlled stations.

STATOR

The stator frame is of rigid mechanical design, being made of cast iron. The laminated core is securely clamped to the frame by means of heavy through bolts. Openings around the outer periphery of the frame allow the free circulation of air for the ventilation of the core and coils.

The core consists of accurately punched laminations of soft steel of a special grade adopted by the General Electric Company as a standard for this work after many years of experimenting. These laminations are carefully annealed, tested, given an insulating coating and assembled so as to minimize both hysteresis and eddy current losses.

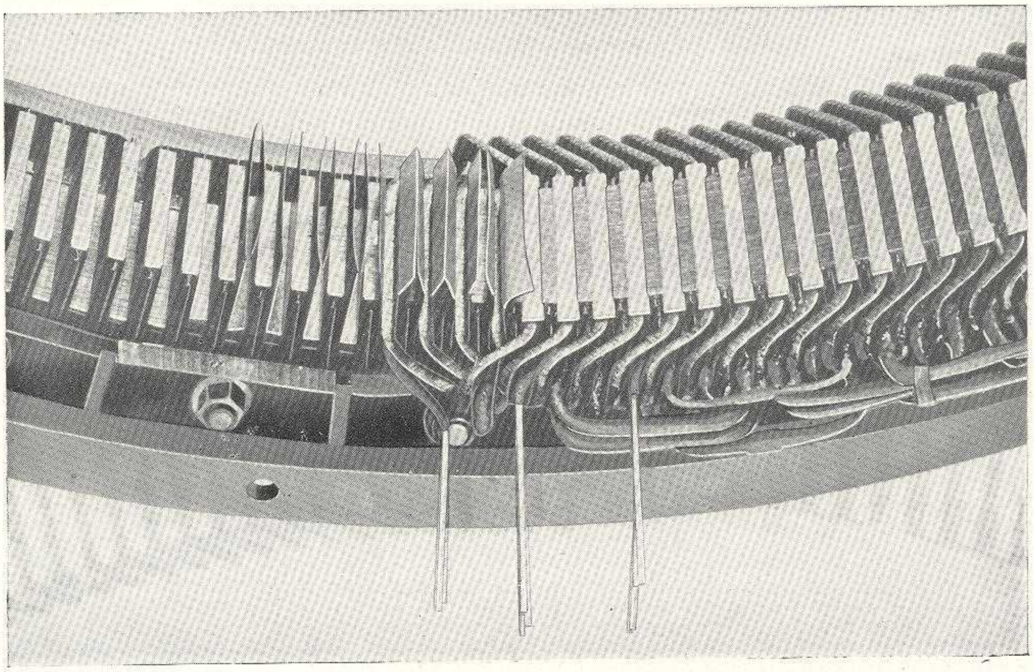
With the same die and at the same time as the laminations are punched from the sheet metal, the slots for receiving the stator coils are also punched, consequently, when assembled, no filing is necessary on the slots. This is an important feature as the filing of the slots would defeat the purpose of insulating the laminations from one another, i.e., to eliminate eddy current losses.



STATOR FRAME

These slots are of the open type, thus allowing the easy installation of the stator coils. The use of fractional instead of an integral number of slots per pole in the design of alternating-current generators gives a smooth wave form free from ripples, resulting in improved efficiency, good parallel operation and a reduction in the possibility of disturbance on telephone lines in close proximity to the generator lines. This fact has been recognized by the General Electric Company for many years and the use of fractional slots adopted in the manufacture of its alternating-current generators.

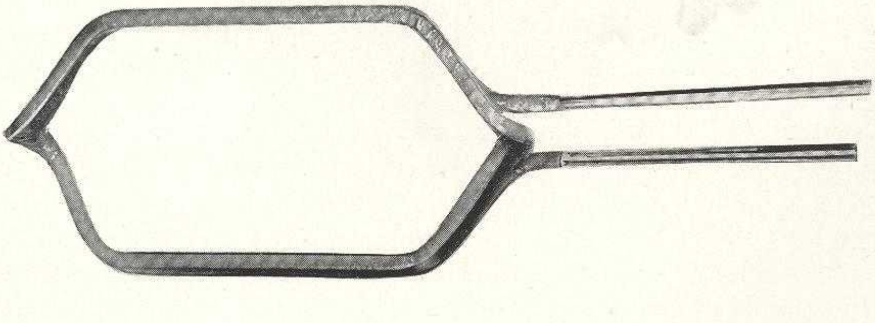
The tooth supports at the ends of the core are spot welded to the end laminations, thus firmly securing them from any displacement. Firmly clamping the teeth, they prevent any abrasion of the coil insulation or vibration of the laminations. These tooth supports or clamping fingers do not touch each other at the back of the core, thus insuring a free circulation of air through the coils as they project from the core. Air circulation through the core itself is provided for by means of ducts formed by suitable spacing blocks open at both ends, which are inserted at intervals between the laminations.



SECTION OF STATOR FRAME SHOWING METHOD OF INSTALLING COILS

The stator coils are form wound, uniform in shape and size, thus being interchangeable, and readily replaced in case of injury. Inasmuch as the life of an alternator depends, to a large degree, on the insulation of its winding, great care is given to the insulation of the stator coils. They are taped and treated with an impregnating compound, the materials used being carefully selected to avoid deterioration or diminution of the dielectric strength through aging. The insulation of these coils conforms strictly to the requirements of the American Institute of Electrical Engineers. After being tested, the coils are inserted in the stator slots in an armor of horn fiber, being held in place by retaining wedges of treated hard wood dovetailed into the slot walls. The conductors of the stator winding are of ample cross section, having a large current carrying capacity, thus insuring operation with safe temperature rise and minimum copper loss.

Attention is called to the fact that the stator windings of G-E alternators are designed with as high a reactance as is compatible with high efficiency and good voltage control, which minimizes the possibility of injury to the machine from short circuits which may occur on the line. In modern practice, low inherent regulation of an alternator is of small consideration as perfect voltage control is easily obtained by use of the G-E automatic voltage regulator.



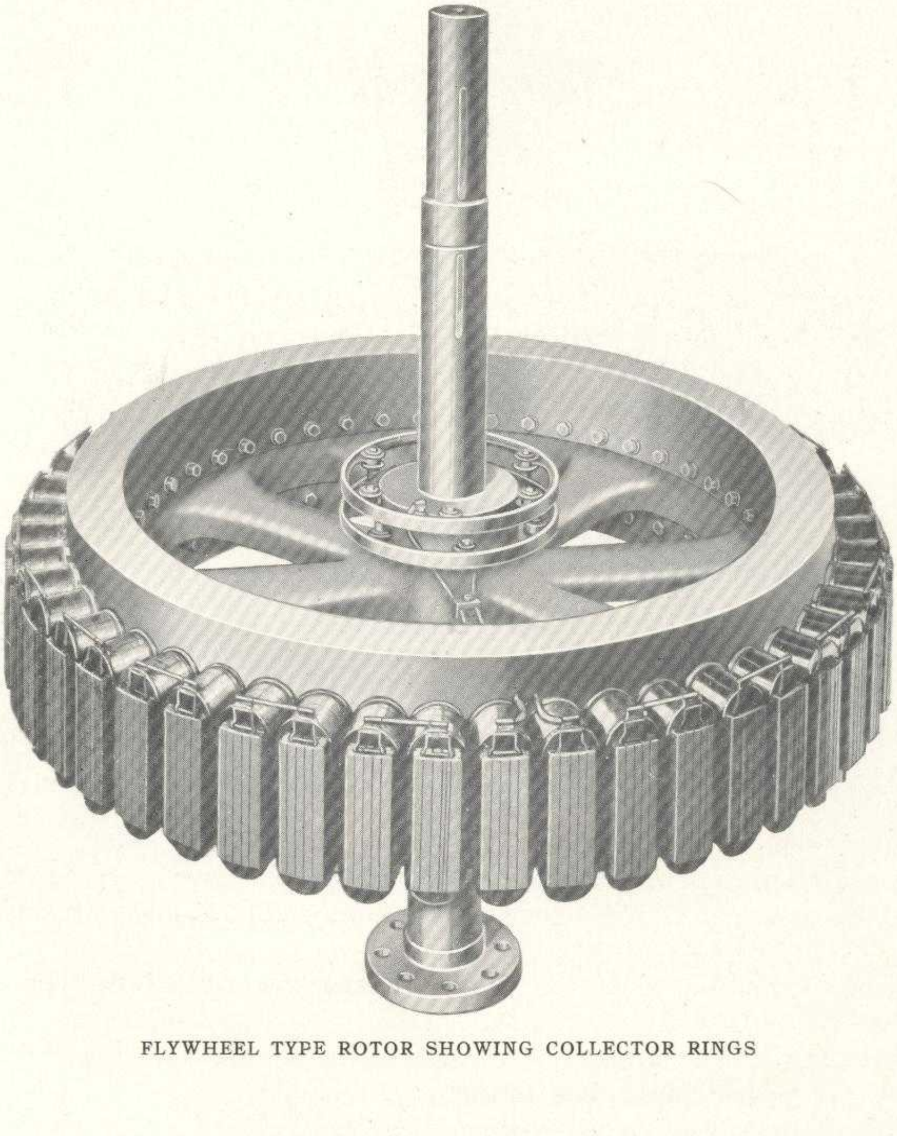
ARMATURE COIL

ROTOR

The revolving field or rotor consists of pole pieces with their windings mounted on a circular cast iron or steel spider of high magnetic quality. The rotor spiders of standard machines are made solid, but, in special cases, split rotors may be furnished. These rotor spiders are made with extra heavy rims in order to obtain the maximum amount of WR^2, or flywheel effect, consistent with good mechanical and electrical design.

As waterwheels are subject to the remote possibility of loss of speed control, the stresses encountered in generator rotors at runaway speed are several times normal. The rotors of all G-E alternating-current generators are designed to withstand DOUBLE SPEED. For slow and moderate speed generators the rotor spider is made of cast iron or steel. Those of high speed machines are made of laminated steel.

The arms of the rotor spiders are made stiff enough to support the weight of the entire rotating element when the spider is blocked up at the rim for assembly or disassembly.

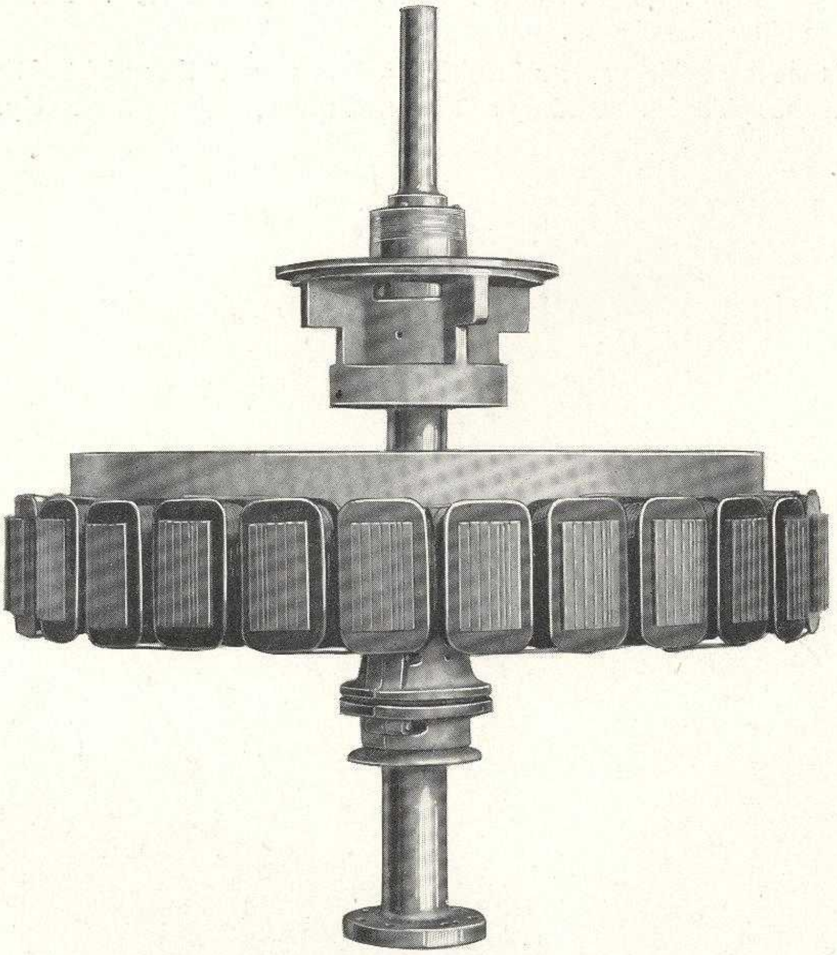


FLYWHEEL TYPE ROTOR SHOWING COLLECTOR RINGS

FLYWHEEL EFFECT AND PARALLEL OPERATION

The rotor spiders of these machines are made with extra heavy rims to obtain the maximum amount of flywheel effect consistent with good design, thus avoiding excessive speed fluctuations in the prime mover. In case there is insufficient flywheel effect in the generator rotor a separate flywheel can be provided to be mounted on a boss on the waterwheel shaft.

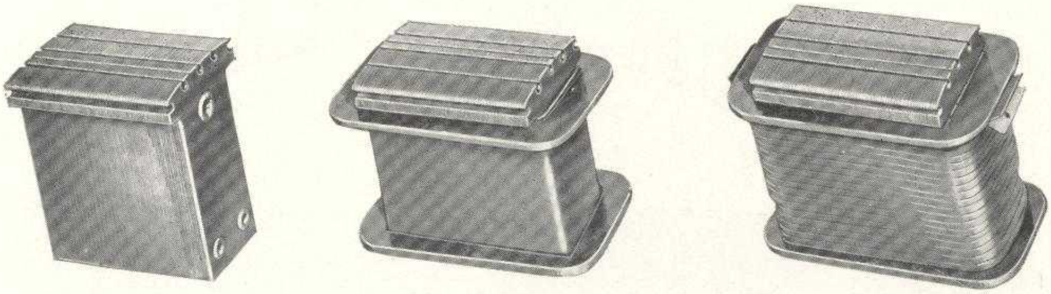
The use of fractional slots per pole and the proper design of pole pieces, giving in a generator a wave form closely following the sine curve, results in parallel operation more nearly perfect for all conditions of load and power-factor. The accuracy of the modern waterwheel governor is such that alternators in most modern hydro-electric plants can be safely arranged for parallel operation and in many instances alternators in widely separated power plants are being successfully operated in parallel.



FLYWHEEL TYPE ROTOR WITH THRUST AND GUIDE BEARINGS ASSEMBLED

The pole pieces are built up of soft steel laminations securely riveted together. On slow and moderate speed machines they are secured to the spider by means of bolts. On high speed machines they are securely dovetailed into the rotor spider and locked by steel keys, the keys being guarded by castings or rings bolted to the rotor rim.

The field coils, except those of the larger machines, are made of copper wire wound directly on the pole piece in such manner as to expose the wire surface to the air and thus insure good ventilation. The winding of these coils directly on the poles insures against any possibility of their becoming loose while the machine is in operation; furthermore, the possibility of air pockets between the winding and pole body is eliminated. On machines of larger size the coils are of copper strip, wound edgewise, each turn being thoroughly insulated from the other by heat-resisting material. As each turn is therefore exposed to the air, the best possible radiation of heat is insured. The pole pieces are thoroughly insulated from either strip- or wire-wound coils by a wrapping of fiber insulation.

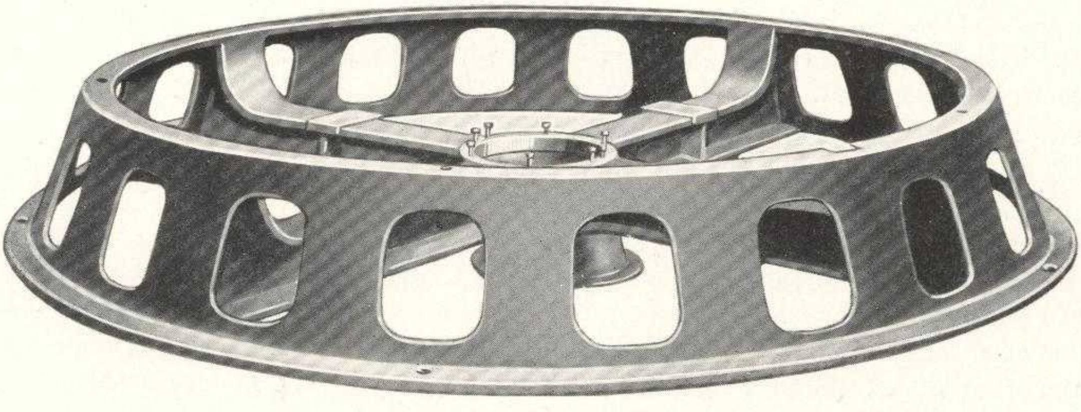


FIELD POLES AND WINDING

BASE AND LOWER BEARING BRACKET

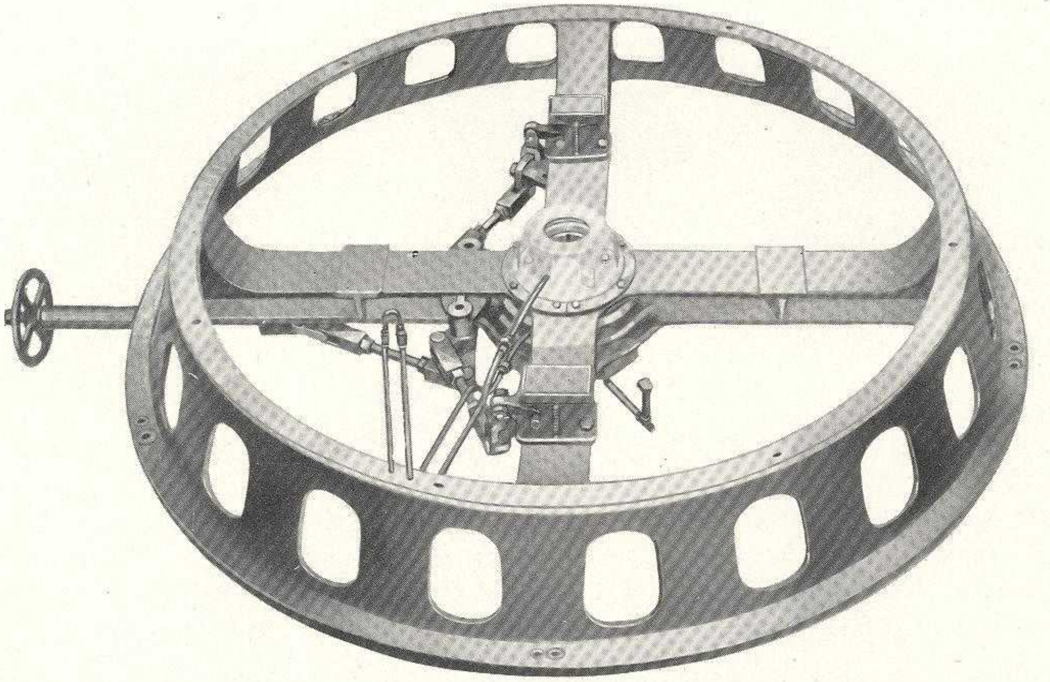
For machines of small diameter the base and lower bearing bracket are made in one piece. This piece is doweled to the stator frame and also to small foundation plates which are grouted in the concrete. The flare on the base is designed to provide adequate opening for removing the waterwheel parts when required.

For machines of larger diameter the lower bearing bracket is a separate piece, and heavy foundation caps are used instead of a base. This separate lower bearing bracket is of such diameter that it may be lifted through the stator of the generator.



COMBINED BASE AND LOWER BEARING BRACKET

In all cases the arms of the lower bearing bracket are provided with pads on which brakes may be mounted and are strong enough to support the total weight of the rotating element. This lower bearing bracket supports the babbitt lined lower guide bearing which is split and can be removed without disturbing any other part of the machine. The lower bearing is lubricated by means of an oil pump located in a split oil pan which is bolted to the lower end of the bearing housing. The pump is of a very simple and rigid construction and is operated by a cam on the generator shaft. The oil is forced through piping, extending outside the base ring, to the upper surface of the bearing and the flow of oil can always be examined by simply removing the "U" shaped cap in the pipe outside the base. Any overflow of oil from the top of the bearing returns immediately to the oil pan.



COMBINED BASE AND LOWER BEARING BRACKET WITH LOWER GUIDE BEARING AND MECHANICAL BRAKES

SHAFT

Keyed to the rotor is the steel shaft, which is of ample cross section to insure strength and rigidity. The flange type coupling is forged solid with the shaft, thus insuring perfect alignment with the waterwheel shaft. Coupling bolts are not furnished unless specified, as they are usually supplied by the waterwheel builder.

UPPER BEARING BRACKET

The upper bearing bracket which supports the combined self-oiled spring thrust and upper guide bearing and brush-holders is rigidly designed to carry the weight of the generator rotor, waterwheel runner shaft and hydraulic thrust. It is made in one piece having radial arms, the space between these arms being covered with perforated sheet metal covers, thus permitting the free circulation of air through the generator. Adjusting bolts in the rim enable exact adjustment of clearances at any time.

*THRUST BEARING

The combination spring supported thrust and upper guide bearing is of the simplest type now in use and has been developed by the General Electric Company in an effort to overcome certain difficulties experienced with other types of bearings. Spring supported thrust bearings

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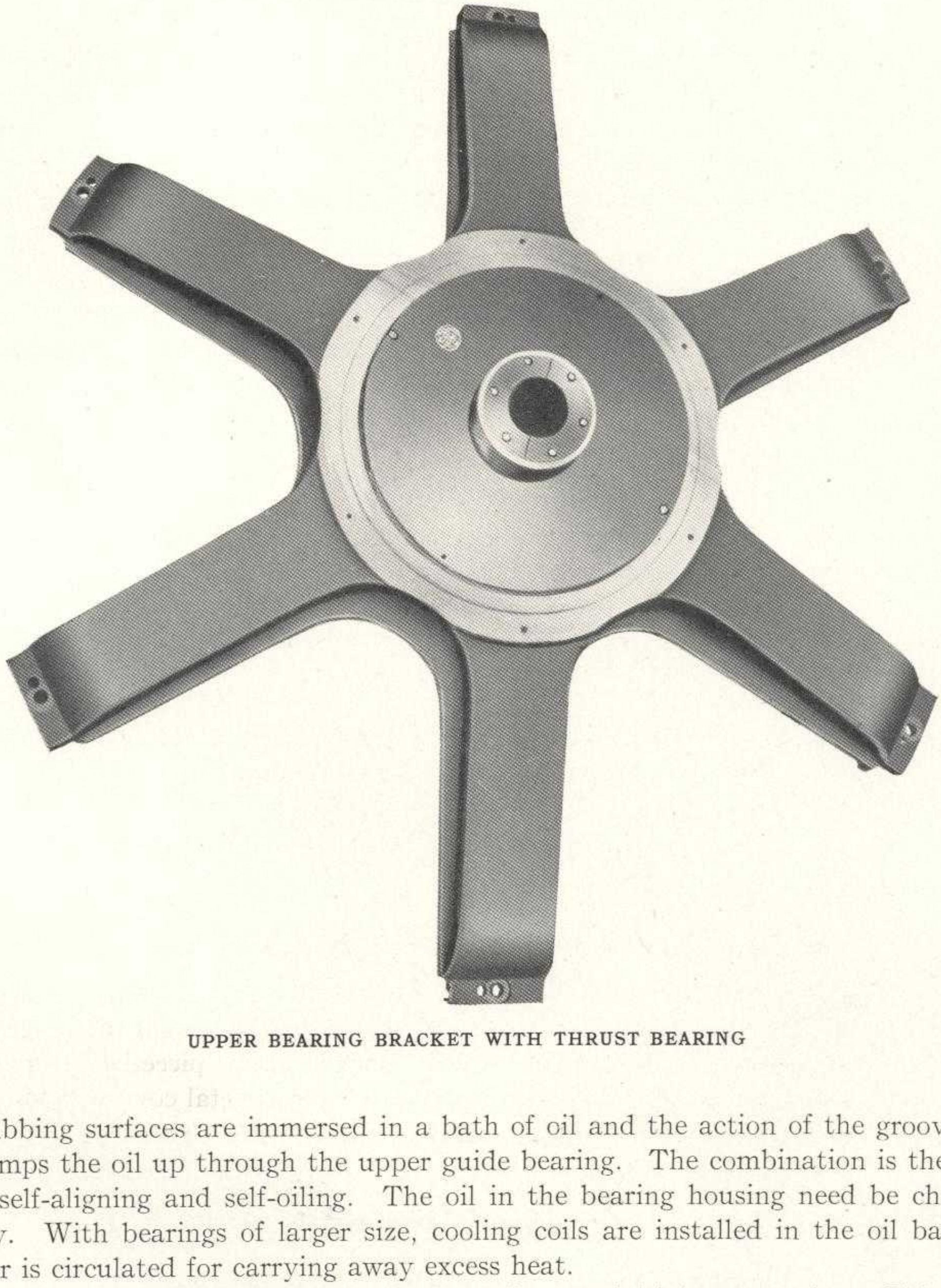
*Bulletin No. 49710B

are now in successful operation carrying up to 1,000,000 pounds. The simple construction of this bearing avoids the purchase of expensive parts for replacement in case of wear or accidental damage. Of the many types on the market it is the only one which automatically adjusts itself to unequal loading due to inaccuracies in workmanship or alignment. While some other types of bearings may be properly adjusted when installed, a distinctive feature of the spring supported bearing is that it will automatically adjust itself while in operation if there is loss of alignment due to settling of foundations or to other causes. Bearings of other construction may not align themselves under such condition.



UPPER BEARING BRACKET WITH THRUST BEARING

The rubbing surfaces are immersed in a bath of oil and the action of the grooves in these surfaces pumps the oil up through the upper guide bearing. The combination is therefore self-contained, self-aligning and self-oiling. The oil in the bearing housing need be changed only occasionally. With bearings of larger size, cooling coils are installed in the oil bath through which water is circulated for carrying away excess heat.

When installed in the bearing the springs are given an initial compression. This insures the maintenance of the required clearance between the waterwheel runner and its casing when the weight of the runner and hydraulic thrust is added to that of the generator rotor.

The thrust collar which supports the rotating element is held rigidly in place by a split retaining ring mortised into the shaft and is easily removable. This type of support prevents any possible injury to the shaft and insures the same position of the waterwheel runner with respect to its casing.

The use of the spring supported thrust bearing and thrust collar has been adopted by the General Electric Company for its large generators where the weight of the rotating element is very heavy. Such eminently satisfactory results have been obtained both from the standpoint of operation and assembly that their use has been adopted on these smaller generators.

BRUSH-HOLDER AND COLLECTOR RINGS

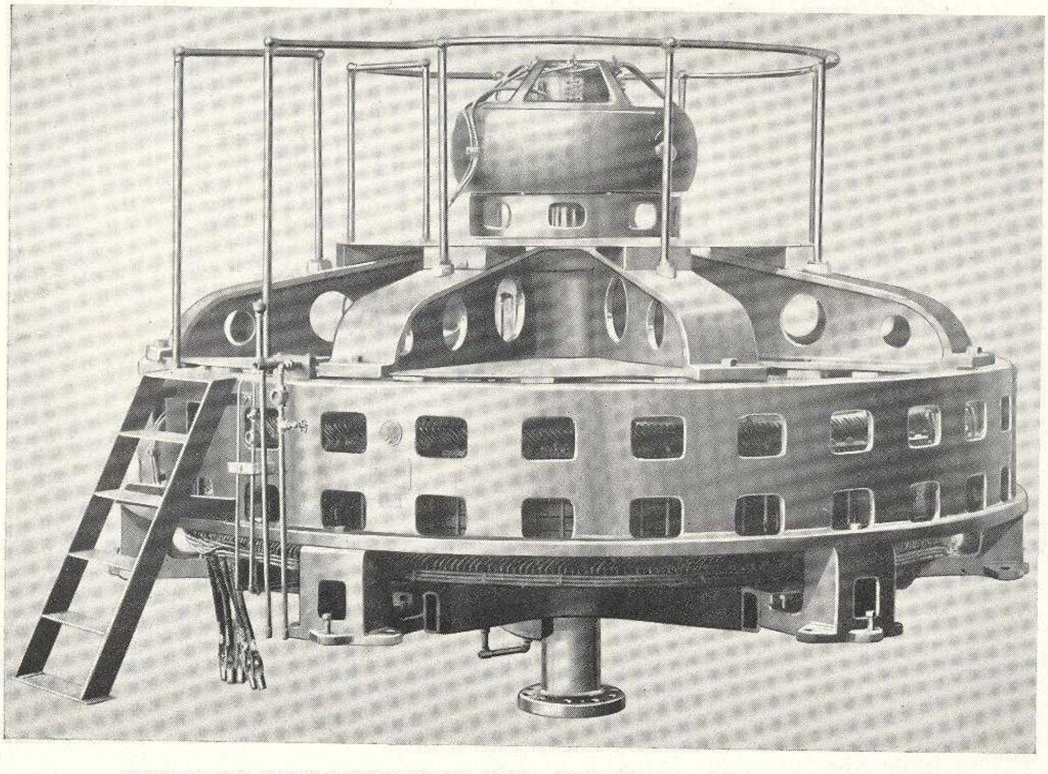
The brush-holders mounted on the upper bearing bracket are equipped with springs of high grade, insuring a constant and even pressure of the brushes on the collector rings. Carbon brushes of ample current carrying capacity are used, being staggered in order to prevent uneven wear or pitting of the collector rings. The collector rings mounted on the shaft are made of cast iron and are so designed that all surfaces of the rings have easy access to air, thus insuring good ventilation.

STAIRWAYS, HANDRAILS AND FLOORPLATES

Whenever desired, stairways, handrails and floorplates can be furnished to enable the operator to go on top the generator frame for examination of the thrust bearing, collector rings, brushes, or direct connected exciter.

LIFTING DEVICE

Whenever desired, a lifting device or trunnion can be furnished for lifting the rotor. The use of an eyebolt in the end of the shaft for lifting the rotor is not recommended.



GENERATOR WITH FOUNDATION CAPS, STAIRWAY, PLATFORM AND RAILS

RATINGS

G-E vertical waterwheel-driven generators are conservatively rated on the basis of energy output at 80 per cent power-factor and are, therefore, especially adapted for carrying either mixed lighting and power load, or an induction motor load alone.

In accordance with A.I.E.E. Standardization rules all sizes are continuous rated and will deliver the rated kilovolt-amperes at any power-factor between unity and 0.8 at a temperature rise not exceeding 50 degrees C. by thermometer under continuous operation.

PHASES AND VOLTAGES

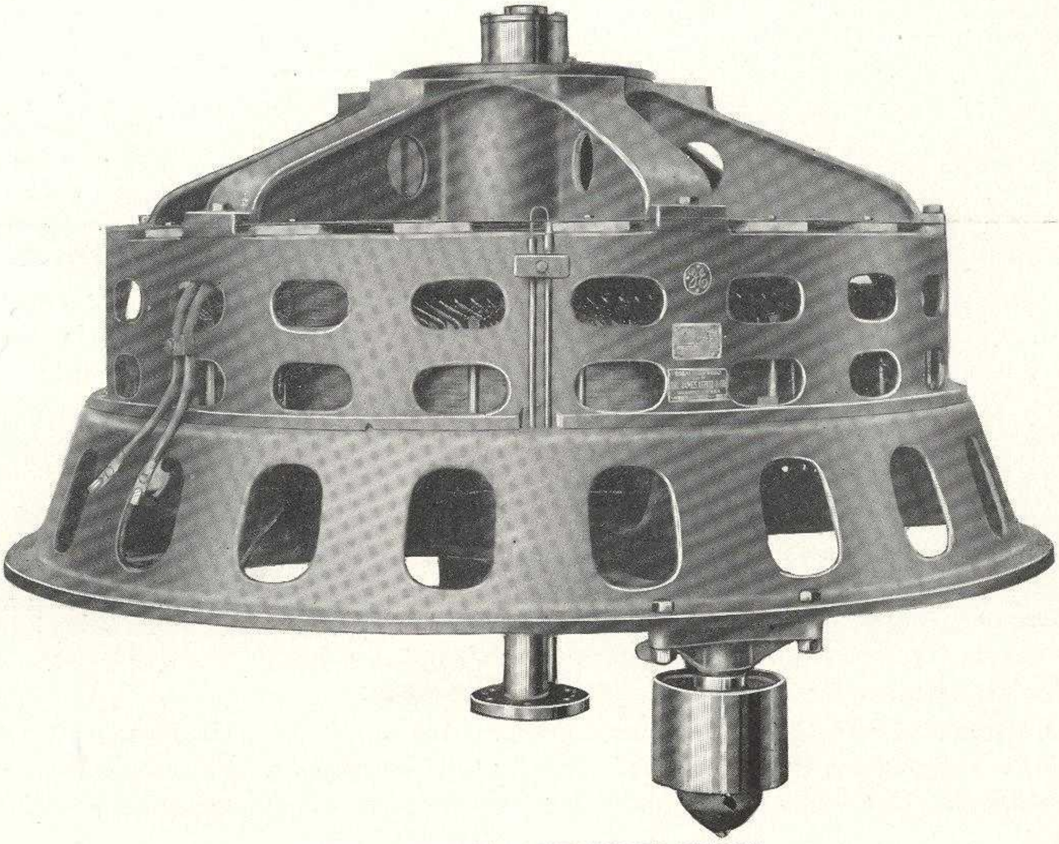
These generators can be furnished either three-phase or two-phase. Where single-phase is desired the three-phase windings can be used at reduced rating.

For the generators of smaller capacity which this bulletin is intended to cover, the standard voltages are 2300, 600, 480 and 240 volts.

EXCITATION

The standard method of supplying excitation for these alternators is by a direct connected exciter, the armature of which is carried on the alternator shaft, and the magnet frame bolted to the upper bearing bracket. Whenever desired the alternator can be provided with a pulley and idler for driving a standard horizontal belted exciter with a quarter turn belt.

All G-E exciters are liberally designed and capable of furnishing the required excitation for low power-factors. The use of the G-E automatic voltage regulator is strongly recommended, by means of which the terminal voltage may be kept practically constant through wide changes



180-KV-A. GENERATOR WITH IDLER PULLEY

in the character of the load and varying conditions of speed. On all standard alternators the field is designed for 125-volt excitation; however, in special cases fields can be supplied for any other excitation voltage.

GUARANTEES

All the high potential tests, temperature rise, and efficiencies given by the General Electric Company on its waterwheel-driven generators are in strict conformity with the rules of the American Institute of Electrical Engineers.

In determining efficiencies the following losses are included: core loss, load loss, I^2R or copper loss in the stator winding (the resistance of the winding being measured at 75 deg. C.); field loss (including rheostat loss when operating exciter at rated voltage or at the rated exciting voltage); friction and windage losses.

The generator rotors are guaranteed to withstand DOUBLE SPEED.

CAPACITIES

The General Electric Company has developed this field of moderate sized vertical generators further than any other manufacturer. In these sizes there are thirty different power ratings of standard design ranging in capacity from 30 kv-a. to 3000 kv-a. and each of the thirty sizes is furnished in an average of nine different speeds. This large list of standard machines insures our ability to exactly suit the user's needs, and enables us to make prompt shipment. Some of the data for the standard machines are given in the table on page 20. This number of machines enables a generator to be selected which fully and efficiently meets all ordinary demands.

The Company is prepared to meet any special conditions by making minor changes in the machines.

Bulletin No. 40600C, Waterwheel-driven Generators, showing many of the larger installations furnished, may be had from the General Electric Company upon request.

TESTING

Thorough tests of all G-E generators are made with respect to both the individual parts and the completed machines in order to insure the purchaser against delay in operation after installation. The rotors are tested for static and running balance to avoid possible vibration in operation. Both the stator and rotor coils are inspected and given tests before and after assembly in the machine. The whole machine is then given a running test to determine its losses, and a final insulation test given the windings. These tests are made to conform to the requirements of the American Institute of Electrical Engineers.

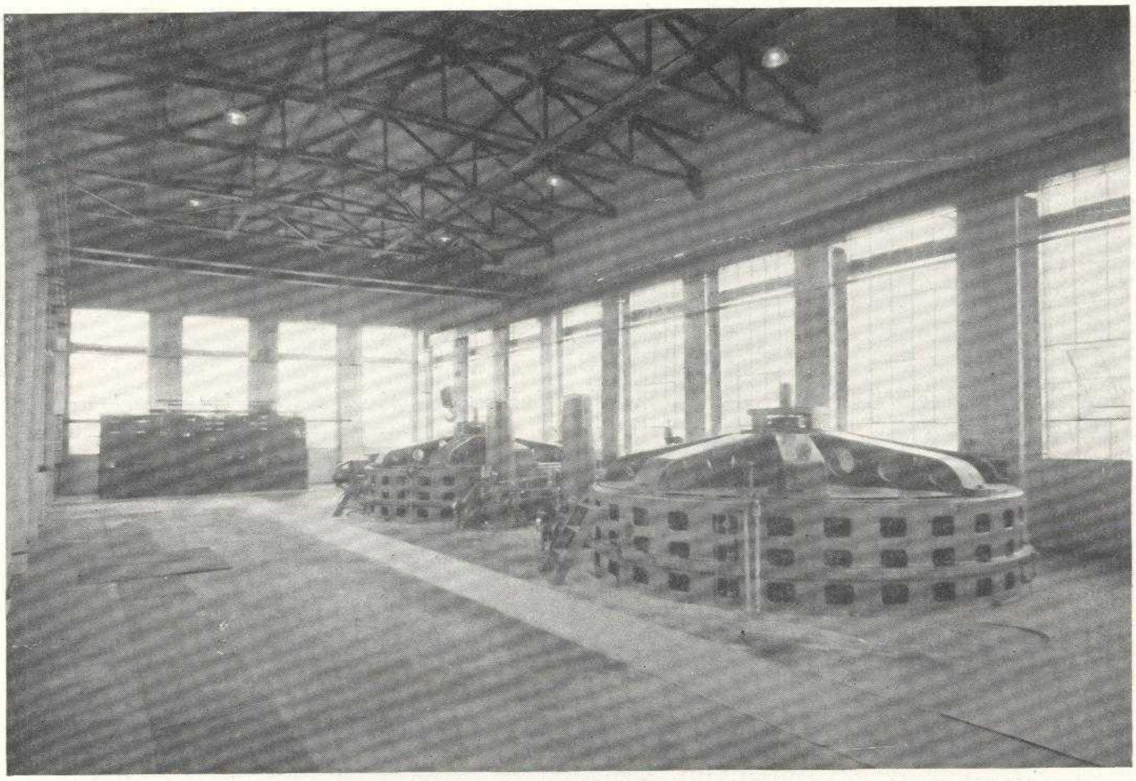
AUTOMATIC GENERATING STATIONS

There are many small streams that could be developed to deliver electric power economically were it not for the expense of keeping one or more operators at the plant continuously. In the past, this has meant the waste of much valuable water power.

The General Electric Company has overcome this difficulty and provided means for developing water power without the necessity of the customary attendants. This is accomplished by means of the so-called "Automatic Generating Stations" and "Remote Controlled Generating Stations."

At the beginning of 1924, the General Electric Company had in operation or on order the equipments for automatically controlling 58 hydro-electric generating stations, having a total capacity of almost 50,000 kv-a. These stations range from one unit of 75 kv-a. to one unit stations of 7300 kv-a. capacity. The number of units in individual stations varied from one to three. During 1924, orders were received for automatic control equipments for stations as high as 24,000 kv-a. capacity.

These plants may be made to start and stop automatically under almost any desired condition, such as water level, or by a timing switch. They may also be designed to be controlled over pilot wires by an operator at some distant point. In some cases this control may be so simple that the operator has merely to close the main switch in the power line leading to the automatic station to start and put the generators in operation and open the same switch to shut them down; all the other operations being entirely automatic.



INTERIOR OF AUTOMATIC HYDRO-ELECTRIC STATION SHOWING TWO 1500-KV-A. GENERATORS AND CONTROL BOARD, HOLYOKE, MASS.

These plants are so designed as to be amply protected against possible short circuit, overheating of the bearings, or other contingencies. They operate successfully with no attendants and require only an occasional inspection. The automatic devices are almost human in their operation and are arranged to shut down the station if there is any serious trouble, and allow it to start only when the symptoms of trouble have disappeared.

Automatic and remote controlled stations when designed by competent and experienced engineers and equipped with reliable machinery, make possible the economical development of water power that would otherwise run to waste. The operation of these plants has amply justified the confidence placed in G-E engineering and apparatus by managers and engineers wherever electrical apparatus is used.

DATA REQUIRED FOR ESTIMATES

(See Formulas Following)

Having determined the available horse power, the question of number, capacity and speed of the turbine units to be installed should be taken up with the waterwheel builders.

The General Electric Company does not manufacture or sell waterwheels, but is prepared to furnish generators at any size or speed, and to co-operate with any of the waterwheel builders.

The following information is required for the preparation of estimates on vertical waterwheel-driven generators:

(1) Maximum horsepower of turbine
(2) Horsepower of turbine at maximum efficiency
(3) Normal speed of turbine
(4) Runaway speed of turbine
(5) Weight of waterwheel runner, shaft and water thrust
(6) Minimum WR^2 (flywheel effect)
(7) Diameter of largest piece of turbine to be removed through concrete foundations or generator floor
(8) Kv-a. rating, power-factor, frequency, phase and voltage of generator
(9) Method of excitation (direct connected, belt driven or motor driven)

GENERAL CONDITIONS

The flow of streams is not constant, but varies constantly from week to week and with the seasons, and is not always the same each year. This is due to the variation in rainfall, evaporation and run-off on any definite watershed and may be great or little depending on climatic conditions which may exist at the time.

Most of the available stream flow data in the United States is contained in the publications of the U. S. Geological Survey. These reports furnish a great deal of valuable data for comparative study of stream flow. Complete files are kept in all state libraries or may be secured at small cost for any desired locality from the Superintendent of Documents, Washington, D. C.

AUXILIARY POWER

In many instances, due to drought or excessive peak demands over short periods, it becomes necessary to add to the normal power that may be derived from a stream. This may be secured in two ways: storage or auxiliary power in some form.

Wherever the topography of the land permits it is often possible to secure adequate pondage, which greatly increases the power that may be derived from a stream. If this method should not prove feasible some form of auxiliary power may be used. The General Electric Company is prepared to furnish steam turbo-generators in any size from 100 kw. to 100,000 kw. capacity as auxiliary equipment, thus assuring not only the most economical hydraulic development as well as reliable standby service at all times.

Every bit of water power that can be used should be developed and conserved. The power lost through inefficient equipment is wasted, and the difference in output between the old style of hydro-electric development and the modern vertical waterwheel-driven apparatus will invariably bring about the production of greater electrical energy shown by much increased kilowatt-hour output and increased income.

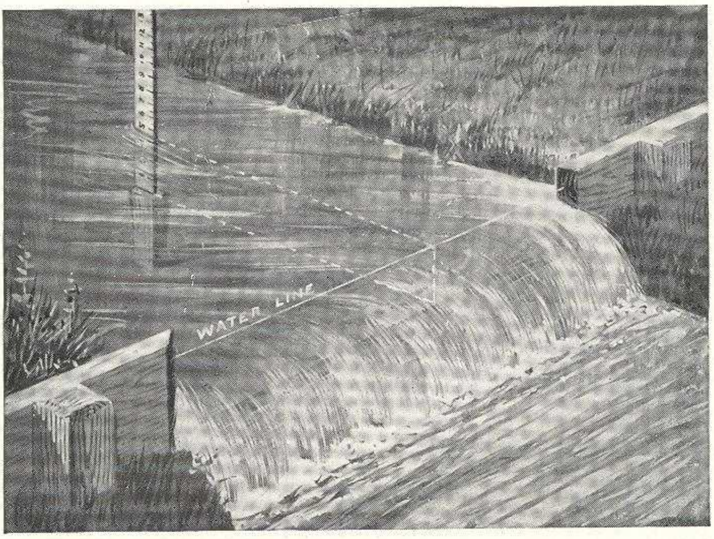
Water power is primarily dependent on two factors: The head and the flow. The "head" is the height of fall, or the difference in elevation between two points on the stream. The "flow" is the volume of water passing in a specified time.

CALCULATION OF POWER

The head is found by direct measurement and the flow can be best determined by one of two generally used methods. The simplest of these is to utilize a weir to measure and compute the flow; but many streams are so large that the use of a weir would be impracticable. It then becomes necessary to find the cross section of the stream by measurement and to ascertain the average velocity by a number of tests at various points.

WEIR

A weir is a sharp crested dam placed so that the water will all flow over it without restriction. It is known that for any given depth of water over the crest of the weir a definite quantity will flow per minute. The factors for this flow have been determined and tabulated. The table on page 18 gives these figures in condensed form, which are accurate enough for any preliminary calculations.



WEIR

METHOD OF WEIR CONSTRUCTION AND MEASUREMENT

Place a board across the stream at some point which will allow a pond to form above. The board should have a notch cut in it with both edges and the bottom sharply beveled toward the intake, as shown in the above cut. The bottom of the notch, which is called the "crest" of the weir, should be perfectly level and the sides vertical.

In the pond back of the weir, at a distance not less than the length of the notch, drive a stake near the bank, with its top precisely level with the crest.

By means of a rule, or a graduated stake as shown, measure the depth of water over the top of the stake, making allowance for capillary attraction of the water against the sides of the rule. For extreme accuracy this depth may be measured to thousandths of a foot by means of a "hook gauge," familiar to all engineers. Having ascertained the depth of water over the stake, refer to table on page 18 from which may be calculated the amount of water flowing over the weir.

There are certain proportions which must be observed in the dimensions of this notch. Its length or width should be between four and eight times the depth of water flowing over the crest of the weir. The pond back of the weir should be at least 50 per cent wider than the notch and of sufficient width and depth that the velocity of flow or approach be not over one foot per second. In order to obtain these results it is advisable to experiment to some extent.